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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of

Richard D. Breault et al — Docket: C-2789

Serial No. 10/668,869 — Art Unit: 1745

Filed: September 22, 2003 — Examiner: Ben Lewis

Title: Internal PEM Fuel Cell Water Management

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

DECLARATION UNDER 37 CFR 1.132

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

I, Richard D. Breault declare that:

1. I reside at 153 Pleasant Street, North Kingstown, RI 02852.

2. I have a Bachelor of Science degree in Chemical Engineering and have been working in the field of fuel cells and related arts for over 43 years, and am currently engaged in that field on behalf of UTC Power Corporation, South Windsor, CT.

3. I am a co-inventor of the subject application and am currently familiar with its content, including claims 18 and 19 and the support for those claims in the specification.

4. The amount of water produced in a fuel cell was widely known, as in US 6,451,466, issued in 2002, from the reaction at the cathode:

$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$;

two gram-moles of water molecules are produced for every four gram-moles of electrons. The Farady constant, on page 778 of *McGraw-Hill Dictionary of Scientific and Technical Terms, Sixth Edition* (Library of Congress data, 2002), copy herewith, is 96,845 C (coulombs) per each gram-mole of water produced. Since four

gram-moles of electrons are produced for two gram-moles of water, 96,845 x 2 = 193,690 coulombs are produced for each mole of water. One coulomb per second is one ampere; thus it is known that 5.1x10^{-6} moles of water are produced per second per ampere of current produced by the fuel cell power plant.

5. The amount of water transferred directly from cathodes to anodes through the water transfer capability or path is controlled (as is explained at page 4, line 24 through page 5, line 15 of the subject application) in response to a pressure differential between the cathode and the anode. The relationship between the pressure differential and the rate of flow (volume per unit of time) of water has been, before September 2003, determined routinely using Darcy's law, described in a contemporaneous printout from Wikipedia, herewith, but also described on page 546 of the 2002 edition of *McGraw-Hill* (hereinbefore), copy herewith.

Since the cathode-to-anode water transfer path will have been designed by, made, and installed by or under the direction of the same skilled artisan who will determine the flow from cathodes to anodes, the permeability, area of flow and length of flow of the water transfer path will be known by that artisan. The viscosity of water around 80°C (for instance) is shown on pages 6-2 and 6-175 of the *Handbook of Chemistry and Physics, 86th Edition* (2006), copy herewith. Viscosity at other temperatures was available from standard tables, such as earlier editions of the *Handbook*. Thus, the establishment of a desired volume of water per unit of time through the water transfer capability or path was a routine matter before September, 2003.

6. The amount of water being discharged from the anodes, through the anode water transport plates, to ambient has routinely been measured by flow meters, well known prior to September, 2003, as shown on page 825 of *McGraw-Hill*, (hereinbefore), copy herewith. This amount is adjusted by varying the cathode-to-anode flow as described in paragraph 5, hereinbefore.

7. The amount of water vapor in the cathode gas flow field exhaust can easily be determined by simply condensing the vapor, as shown in US 5,998,058, issued in 1999, and measuring the flow of water to ambient with a known flow meter.

It was standard knowledge before September, 2003 that the amount of water in a flow of gas, such as the cathode gas flow field exhaust, can also be

determined from the total mass flow, temperature, total pressure, and vapor pressure of water. The vapor pressure of water at a temperature, is found in well-known tables, such as at pages 6-8 of the *Handbook* (hereinbefore) and earlier editions thereof. The mass flow (moles) of water is simply the total flow times the ratio of vapor pressure to total pressure.

8. The creation of flows set forth in either of claim 18 or claim19 begins by establishing the current to be produced by the stack. From the current, the product water is routinely calculated as described in paragraph 4, hereinbefore. The coolant temperature, and therefore the temperature at the reactant gas exits of the stack is controlled as shown in US 2002/0148608 A1. The pressure of anode and cathode, and thus their relative pressure, is adjustable as shown in US 2001/0004501 A1, to cause the desired cathode-to-anode water flow of the invention, as described in paragraph 5, hereinbefore. The experimentation required by one skilled in the fuel cell arts to balance the cathode exit temperature and the cathode/anode pressure differential, while measuring anode water transport plate outflow and cathode vapor outflow, is routine and easily completed in a matter of hours.

9. All statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true and further that these statements are made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Richard D. Breault — December 21, 2007

Richard D. Breault — Date

Darcy's law

From Wikipedia, the free encyclopedia

In fluid dynamics, **Darcy's law** is a phenomologically derived constitutive equation that describes the flow of a fluid through a porous medium. The law was formulated by Henry Darcy based on the results of experiments[1] on the flow of water through beds of sand. It also forms the scientific basis of fluid permeability used in the earth sciences.

Contents

Background

Although Darcy's law (an expression of conservation of momentum) was determined experimentally by Darcy, it has since been derived from the Navier-Stokes equations via homogenization. It is analogous to Fourier's law in the field of heat conduction, Ohm's law in the field of electrical networks, or Fick's law in diffusion theory.

One application of Darcy's law is to water flow through an aquifer. Darcy's law along with the equation of conservation of mass are equivalent to the groundwater flow equation, one of the basic relationships of hydrogeology. Darcy's law is also used to describe oil, water, and gas flows through petroleum reservoirs.

Description

Darcy's law is a simple proportional relationship between the instantaneous discharge rate through a porous medium, the viscosity of the fluid and the pressure drop over a given distance.

$$Q = \frac{-\kappa A}{\mu}\frac{(P_b - P_a)}{L}$$

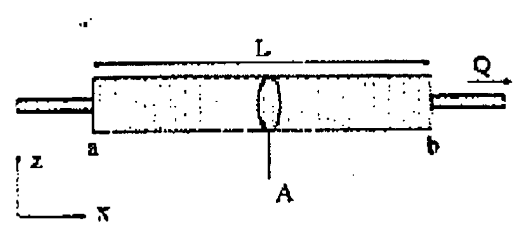

Diagram showing definitions and directions for Darcy's law.

The total discharge, Q (units of volume per time, e.g., m^3/s) is equal to the product of the permeability (κ units of area, e.g. m^2) of the medium, the cross-sectional area (A) to flow, and the pressure drop ($P_b - P_a$), all divided by the dynamic viscosity μ (in SI units e.g. kg/(m·s) or Pa·s), and the length L the pressure drop is taking place over. The negative sign is needed because fluids flows from high pressure to low pressure. So if the change in pressure is

negative (in the x-direction) then the flow will be positive (in the x-direction). Dividing both sides of the equation by the area and using more general notation leads to

$$q = \frac{-\kappa}{\mu} \nabla P$$

where q is the flux (discharge per unit area, with units of length per time, m/s) and ∇P is the pressure gradient vector. This value of flux, often referred to as the Darcy flux, is not the velocity which the water traveling through the pores is experiencing[2].

The pore velocity (v) is related to the Darcy flux (q) by the porosity (φ). The flux is divided by porosity to account for the fact that only a fraction of the total formation volume is available for flow. The pore velocity would be the velocity a conservative tracer would experience if carried by the fluid through the formation.

$$v = \frac{q}{\phi}$$

In 3D

In three dimensions, gravity must be accounted for, as fluid will not flow vertically as a result of the vertical gravitational pressure drop (this is hydrostatic conditions). The correction is to subtract the gravitational pressure drop from the existing pressure drop in the equation in order to express the resulting fluid flow,

$$\boldsymbol{q} = \frac{-\boldsymbol{\kappa}}{\mu} (\nabla P - \rho g \hat{\mathbf{e}}_z)$$

where the flux $\boldsymbol{q}$ is now a vector quantity, $\boldsymbol{\kappa}$ is a tensor of permeability, ∇ is the gradient operator in 3D, g is the acceleration due to gravity, $\hat{e}_z$ is the unit vector in the vertical direction, pointing downwards and ρ is the density.

Effects of anisotropy are addressed in three-dimensions using a symmetric second-order tensor of permeability:

$$\boldsymbol{\kappa} = \begin{bmatrix} \kappa_{xx} & \kappa_{xy} & \kappa_{xz} \\ \kappa_{yx} & \kappa_{yy} & \kappa_{yz} \\ \kappa_{zx} & \kappa_{zy} & \kappa_{zz} \end{bmatrix}$$

where the magnitudes of permeability in the x, y, and z component directions are specified. Since this a symmetric matrix, there are *at most* six unique values. If the permeability is isotropic (equal magnitude in all directions), then the diagonal values are equal, $\kappa_{xx} = \kappa_{yy} = \kappa_{zz} > 0$, while all other components are 0. The permeability tensor can be interpreted through an evaluation the relative magnitudes in each component. For example, rock with highly permeable vertical fractures aligned in the x-direction will have relatively higher values for κ_{xx} than other component values.

Assumptions

Darcy's law is a simple mathematical statement which neatly summarizes several familiar properties that groundwater flowing in aquifers exhibits, including:

- if there is no pressure gradient over a distance, no flow occurs (this is hydrostatic conditions),
- if there is a pressure gradient, flow will occur from high pressure towards low pressure (opposite the

McGRAW-HILL DICTIONARY OF SCIENTIFIC AND TECHNICAL TERMS

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On the cover: Representation of a fullerene molecule with a noble gas atom trapped inside. At the Permian-Triassic sedimentary boundary the noble gases helium and argon have been found trapped inside fullerenes. They exhibit isotope ratios quite similar to those found in meterorites, suggesting that a fireball meteorite or asteroid exploded when it hit the Earth, causing major changes in the environment. *(Image copyright © Dr. Luann Becker. Reproduced with permission.)*

Over the six editions of the Dictionary, material has been drawn from the following references: G. M. Garrity et al., *Taxonomic Outline of the Procaryotes*, Release 2, Springer-Verlag, January 2002; D. W. Linzey, *Vertebrate Biology*, McGraw-Hill, 2001; J. A. Pechenik, *Biology of the Invertebrates*, 4th ed., McGraw-Hill, 2000; *U.S. Air Force Glossary of Standardized Terms*, AF Manual 11-1, vol. 1, 1972; F. Casey, ed., *Compilation of Terms in Information Sciences Technology*, Federal Council for Science and Technology, 1970; *Communications-Electronics Terminology*, AF Manual 11-1, vol. 3, 1970; P. W. Thrush, comp. and ed., *A Dictionary of Mining, Mineral, and Related Terms*, Bureau of Mines, 1968; *A DOD Glossary of Mapping, Charting and Geodetic Terms*, Department of Defense, 1967; J. M. Gilliland, *Solar-Terrestrial Physics: A Glossary of Terms and Abbreviations*, Royal Aircraft Establishment Technical Report 67158, 1967; W. H. Allen, ed., *Dictionary of Technical Terms for Aerospace Use*, National Aeronautics and Space Administration, 1965; *Glossary of Stinfo Terminology*, Office of Aerospace Research, U.S. Air Force, 1963; *Naval Dictionary of Electronic, Technical, and Imperative Terms*, Bureau of Naval Personnel, 1962; R. E. Huschke, *Glossary of Meteorology*, American Meteorological Society, 1959; *ADP Glossary*, Department of the Navy, NAVSO P-3097; *Glossary of Air Traffic Control Terms*, Federal Aviation Agency; *A Glossary of Range Terminology: White Sands Missile Range, New Mexico*, National Bureau of Standards, AD 467-424; *Nuclear Terms: A Glossary*, 2d ed., Atomic Energy Commission.

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DARK-FIELD ILLUMINATION

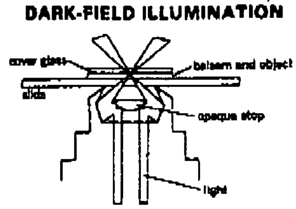


Diagram of dark-field illumination. *(American Optical Corp.)*

is the safety limit for a vessel approaching a dangerous obstacle such as a reef. { 'dān·jər ,aŋ·gəl }

danger area [NAV] A specified area within, below, or over which there may exist activities constituting potential danger to aircraft flying over it, or to persons, property, and traffic on land or sea. { 'dān·jər 'er·ē·ə }

danger bearing [NAV] The bearing of any object or obstruction as measured on board a vessel which will put a ship in jeopardy. { 'dān·jər ,ber·iŋ }

danger buoy [NAV] A buoy marking an isolated danger to navigation. { 'dān·jər ,bòi }

danger coefficient [NUCLEO] The change in reactivity per unit mass of a substance resulting from inserting the substance in a particular nuclear reactor. { 'dān·jər ,kō·i,fish·ənt }

danger line [NAV] A line on a chart representing a boundary, beyond which some hazard will be encountered. { 'dān·jər ,līn }

dangerous semicircle [METEOROL] The half of the circular area of a tropical cyclone having the strongest winds and heaviest seas, where a ship tends to be drawn into the path of the storm. { 'dān·jə·rəs 'sem·i,sər·kəl }

danger sounding [NAV] A minimum sounding chosen for a vessel of specific draft in a given area to indicate the limit of safe navigation. { 'dān·jər ,saùnd·iŋ }

danger space [ORD] **1.** That portion of the range within which a target of given dimensions could be hit by a projectile with a given angle of fall. **2.** Space around the bursting point of an antiaircraft projectile. { 'dān·jər ,spās }

dangler [MET] The flexible electrode used in barrel plating. { 'daŋ·glər }

dangling bond [SOLID STATE] A chemical bond associated with an atom in the surface layer of a solid that does not join the atom with a second atom but extends in the direction of the solid's exterior. { ¦daŋ·gliŋ 'bänd }

dangling ELSE [COMPUT SCI] A situation in which it is not clear to which part of a compound conditional statement an ELSE instruction belongs. { ¦daŋ·gliŋ 'els }

Danian [GEOL] Lowermost Paleocene or uppermost Cretaceous geologic time. { 'dān·ē·ən }

Daniell cell [PHYS CHEM] A primary cell with a constant electromotive force of 1.1 volts, having a copper electrode in a copper sulfate solution and a zinc electrode in dilute sulfuric acid or zinc sulfate, the solutions separated by a porous partition or by gravity. { 'dan·yəl ,sel }

Daniell hygrometer [ENG] An instrument for measuring dew point; dew forms on the surface of a bulb containing ether which is cooled by evaporation into another bulb, the second bulb being cooled by the evaporation of ether on its outer surface. { 'dan·yəl hī'gräm·əd·ər }

Danjon prismatic astrolabe [ENG] A type of astrolabe in which a Wollaston prism just inside the focus of the telescope converts converging beams of light into parallel beams, permitting a great increase in accuracy. { 'dän·yən priz'mad·ik 'as·trə,lāb }

dannemorite [MINERAL] $(Fe,Mn,Mg)_7Si_8O_{22}(OH)_2$ A yellowish-brown to greenish-gray monoclinic mineral consisting of a columnar or fibrous amphibole. { ,dan·ə'mȯr,īt }

dansyl chloride [ORG CHEM] $(CH_3)_2NC_{10}H_6SO_2Cl$ A reagent for fluorescent labeling of amines, amino acids, proteins, and phenols. { 'dans·əl 'klȯr,īd }

Danysz reaction [IMMUNOL] A toxin-antitoxin reaction that occurs when an exact equivalence of toxin is added to antitoxin, not in one portion but in successive increments. { 'dä·nish rē'ak·shən }

DAP *See* diallyl phthalate; diaminopimelate.

Daphniphyllales [BOT] An order of dicotyledonous plants in the subclass Hamamelidae, consisting of a single family with one genus, *Daphniphyllum*, containing about 35 species; dioecious trees or shrubs native to eastern Asia and the Malay region, they produce a unique type of alkaloid and often accumulate aluminum and sometimes produce iridoid compounds. { ,daf·ni·fə'lā·lēz }

daphnite [MINERAL] $(MgFe)_3(Fe,Al)_3(Si,Al)_4O_{10}(OH)_8$ A mineral of the chlorite group consisting of a basic aluminosilicate of magnesium, iron, and aluminum. { 'daf,nīt }

Daphoenidae [PALEON] A family of extinct carnivoran mammals in the superfamily Miacoidea. { də'fēn·ə,dē }

dapsone *See* 4,4′-sulfonyldianiline. { 'dap,sōn }

daraf [ELEC] The unit of elastance, equal to the recipr... of 1 farad. { 'da,raf }

darapskite [MINERAL] $Na_3(NO_3)(SO_4)\cdot H_2O$ A natu... occurring hydrate mineral consisting of a hydrous nitrat... sulfate of sodium. { də'rap,skīt }

Darboux's monodromy theorem [MATH] The propo... that, if the function $f(z)$ of the complex variable z is anal... in a domain D bounded by a simple closed curve C, and is continuous in the union of D and C and is injective for C, then $f(z)$ is injective for z in D. { 'där·büz ¦män·ə,dr... ,thir·əm }

darby [ENG] A flat-surfaced tool for smoothing pl... { 'där·bē }

darcy [PHYS] A unit of permeability, equivalent to th... sage of 1 cubic centimeter of fluid of 1 centipoise visc... flowing in 1 second under a pressure of 1 atmosphere thr... a porous medium having a cross-sectional area of 1 sq... centimeter and a length of 1 centimeter. { 'där·sē }

Darcy number 1 [FL MECH] A dimensionless group, e... to four times the Fanning friction factor. Symbolized ... Also known as Darcy-Weisbach coefficient; resistance co... cient 2. { 'där·sē ,nəm·bər 'wən }

Darcy number 2 [FL MECH] A dimensionless group u... the study of the flow of fluids in porous media, equal t... fluid velocity times the flow path divided by the perme... of the medium. Symbolized Da_2. { 'där·sē ,nəm·bər ...

Darcy's law [FL MECH] The law that the rate at which a ... flows through a permeable substance per unit area is eq... the permeability, which is a property only of the sub... through which the fluid is flowing, times the pressure dr... unit length of flow, divided by the viscosity of the ... { 'där·sēz ,lȯ }

Darcy-Weisbach coefficient *See* Darcy number 1. { ... 'vīs,bäk ,kō·i,fish·ənt }

Darcy-Weisbach equation [FL MECH] An equation ... loss of head due to friction h_f during turbulent flow of ... through a duct of any shape; in the case of a circular pipe ... $f(L/d)(V^2/2g)$, where L and d are the length and diame... the pipe, V is the fluid velocity, g the acceleration of g... and f a dimensionless number called Darcy number 1. ... sē 'vīs,bäk i,kwā·zhən }

dark box [GRAPHICS] A light-proof box used to store light-sensitive photographic papers. { 'därk ,bäks }

dark cloud [ASTRON] A relatively dense, cool cloud of stellar gas, chiefly molecular, whose dust particles obs... light of stars behind it. { 'därk 'klaùd }

dark conduction [ELECTR] Residual conduction in a ... sensitive substance that is not illuminated. { ¦därk k... shən }

dark current *See* electrode dark current. { 'därk ,kər...

dark-current pulse [ELECTR] A phototube dark... excursion that can be resolved by the system employ... phototube. { 'därk ,kər·ənt ¦pəls }

dark discharge [ELECTR] An invisible electrical di... in a gas. { ¦därk 'dis,chärj }

dark-eclipsing variables [ASTRON] A binary star comprising a bright star and an almost dark compan... revolve about each other. { ¦därk ə,klip·siŋ 'ver·ē·ə... }

dark-field illumination [OPTICS] A method of mi... illumination in which the illuminating beam is a hollo... of light formed by an opaque stop at the center of the c... large enough to prevent direct light from entering the o... the specimen is placed at the concentration of the lig... and is seen with light scattered or diffracted by it. ... ,fēld ə,lüm·ə'nā·shən }

dark lightning [GRAPHICS] A photographic effect ... lightning gives black photographic streaks instead ... due to multiple exposures caused by successive ... a composite flash. Also known as Clayden effect. ... ,līt·niŋ }

dark-line spectrum [SPECT] The absorption spec... results when white light passes through a substance, co... of dark lines against a bright background. { 'd... 'spek·trəm }

dark matter [ASTRON] Matter that is postulated to explain the rotational motion of the Milky Way Gal... other galaxies, to explain the motions of galaxies in ... and, in certain cosmological theories, to achieve the...

fan total head [MECH ENG] The sum of the fan static head and the velocity head at the fan discharge corresponding to a given quantity of airflow. { ¦fan ¦tōd·əl ¦hed }

fan total pressure [MECH ENG] The algebraic difference between the mean total pressure at the fan outlet and the mean total pressure at the fan inlet. { ¦fan ¦tōd·əl ¦presh·ər }

fan truss [CIV ENG] A truss with struts arranged as radiating lines. { 'fan ,trəs }

fan vaulting [ARCH] Vaulting in which the ribs diverge like the rays of a fan. { 'fan ,vŏlt·iŋ }

fan velocity pressure [MECH ENG] The velocity pressure corresponding to the average velocity at the fan outlet. { 'fan və'läs·əd·ē ,presh·ər }

FAQ *See* Frequently Asked Questions.

farad [ELEC] The unit of capacitance in the meter-kilogram-second system, equal to the capacitance of a capacitor which has a potential difference of 1 volt between its plates when the charge on one of its plates is 1 coulomb, there being an equal and opposite charge on the other plate. Symbolized F. { 'fa,rad }

faradaic current *See* faradic current. { ,far·ə¦dā·ik ¦kər·ənt }

faraday [PHYS] The electric charge required to liberate 1 gram-equivalent of a substance by electrolysis; experimentally equal to 96,485.3415 ± 0.0039 coulombs. Also known as Faraday constant. { 'far·ə,dā }

Faraday birefringence [OPTICS] Difference in the indices of refraction of left and right circularly polarized light passing through matter parallel to an applied magnetic field; it is responsible for the Faraday effect. { 'far·ə,dā ,bī·ri'frin·jəns }

Faraday cage *See* Faraday shield. { 'far·ə,dā ,kāj }

Faraday constant *See* faraday. { 'far·ə,dā ,kän·stənt }

Faraday cylinder [ELEC] 1. A closed, or nearly closed, hollow conductor, usually grounded, within which apparatus is placed to shield it from electrical fields. 2. A nearly closed, insulated, hollow conductor, usually shielded by a second grounded cylinder, used to collect and detect a beam of charged particles. { 'far·ə,dā ,sil·ən·dər }

Faraday dark space [ELECTR] The relatively nonluminous region that separates the negative glow from the positive column in a cold-cathode glow-discharge tube. { 'far·ə,dā 'därk ,spās }

Faraday disk machine [ELECTROMAG] A device for demonstrating electromagnetic induction, consisting of a copper disk in which a radial electromotive force is induced when the disk is rotated between the poles of a magnet. Also known as Faraday generator. { 'far·ə,dā 'disk mə,shēn }

Faraday effect [OPTICS] Rotation of polarization of a beam of linearly polarized light when it passes through matter in the direction of an applied magnetic field; it is the result of Faraday birefringence. Also known as Faraday rotation; Kundt effect; magnetic rotation. { 'far·ə,dā i'fekt }

Faraday generator *See* Faraday disk machine. { 'far·ə,dā 'jen·ə,rād·ər }

Faraday ice bucket experiment [ELEC] Experiment in which one lowers a charged metal body into a pail and observes the effect on an electroscope attached to the pail, with and without contact between body and pail; the experiment shows that charge resides on a conductor's outside surface. { 'far·ə,dā 'īs ,bək·ət ik,sper·ə·mənt }

Faraday rotation *See* Faraday effect. { 'far·ə,dā rō'tā·shən }

Faraday rotation experiment [ELECTROMAG] An experiment in which a wire dipping in a pool of mercury surrounding a magnet rotates around the magnet when a current passes through it, demonstrating the effect of a magnetic field on a current-carrying conductor. { ¦far·ə,dā rō'tā·shən ik,sper·ə·mənt }

Faraday rotation isolator *See* ferrite isolator. { 'far·ə,dā rō'tā·shən 'īs·əl,ād·ər }

Faraday screen *See* Faraday shield. { 'far·ə,dā ,skrēn }

Faraday shield [ELEC] Electrostatic shield composed of wire mesh or a series of parallel wires, usually connected at one end to another conductor which is grounded. Also known as Faraday cage; Faraday screen. { 'far·ə,dā ,shēld }

Faraday's law of electromagnetic induction [ELECTROMAG] The law that the electromotive force induced in a circuit by a changing magnetic field is equal to the negative of the rate of change of the magnetic flux linking the circuit. Also known as law of electromagnetic induction. { 'far·ə,dāz 'lȯ əv i¦lek·trō,mag¦ned·ik in'dək·shən }

Faraday's laws of electrolysis [PHYS CHEM] 1. The amount of any substance dissolved or deposited in electro... tional to the total electric charge passed. 2. Th... different substances dissolved or desposited by... the same electric charge are proportional to th... weights. { 'far·ə,dāz ¦lȯz əv i,lek'träl·ə·səs }

Faraday tube [ELEC] A tube of force for ele... ment which is of such size that the integral ov... across the tube of the component of electric disp... pendicular to that surface is unity. { 'far·ə,dā...

faradic current Also spelled faradaic current. ... electric current that corresponds to the reductio... of a chemical species. [ELEC] An intermitte... metrical alternating current like that obtained fro... ary winding of an induction coil. { fə'rad·ik...

faradization [BIOPHYS] Use of a faradic curr... muscles and nerves. { ,far·əd·ə'zā·shən }

farcy *See* glanders. { 'fär·sē }

far-end crosstalk [COMMUN] Crosstalk that... the disturbed circuit in the same direction as desi... that circuit. { ¦fär ¦end 'krȯs,tȯk }

farewell buoy *See* sea buoy. { 'fer,wel ,bȯi }

Farey sequence [MATH] The Farey sequenc... is the increasing sequence, from 0 to 1, of fr... denominator is equal to or less than *n*, with... expressed in lowest terms. { 'far·ē ,sē·kwəns }

far field *See* Fraunhofer region. { ¦fär ¦fēld }

farinaceous [BIOL] Having a mealy surf... [FOOD ENG] 1. Containing starch or flour... texture of meal. [GEOL] Of a rock or sedim... texture that is mealy, soft, and friable, for exampl... or a pelagic ooze. { ¦far·ə¦nā·shəs }

Farinales [BOT] An order that includes ... regarded as orders of the Commelinidae in oth... classification. { ,far·ə'nā·lēz }

far-infrared maser [ENG] A gas maser that gen... having a wavelength well above 100 micromete... up to the present lower wavelength limit of abou... ters for microwave oscillators. { ¦fär in·frə'red...

far-infrared radiation [ELECTROMAG] Infrared... wavelengths of which are the longest of those... region, about 50–1000 micrometers; requires d... ings for spectroscopic analysis. { ¦fär in·frə... shən }

Farinosae [BOT] The equivalent name ... { ,far·ə'nō·sē }

farinose [AGR] Yielding farina, a fine meal... matter. [BIOL] Covered with a white powd... { 'far·ə,nōs }

farm [AGR] A tract of land used for cultiva... raising animals. { färm }

Farmer dosimeter [NUCLEO] A small ioniza... with an air wall, used for routine measurement... { ¦fär·mər dō'sim·əd·ər }

farmer's lung [MED] An acute pulmonary di... by the inhalation of spores from moldy hay or ... mərz ,ləŋ }

farmer's year [CLIMATOL] In Great Britain... period starting with the Sunday nearest Ma... mərz 'yir }

farming [AGR] The skills and practices ... { 'fär·miŋ }

farmstead [AGR] The whole area that cons... including its land and buildings. { 'färm,sted }

farnesol [BIOCHEM] $C_{15}H_{25}OH$ A colorl... tracted from oils of plants such as citronella, ner... and tuberose; it has a delicate floral odor, and is a... step in the biological synthesis of cholesterol fr... acid in vertebrates; used in perfumery. { 'fär·n...

Farnsworth image dissector tube *See* image d... { 'färnz,wərth 'im·ij di,sek·tər ,tüb }

far point [OPTICS] The farthest point from a... an object is distinctly seen; for a normal eye it ... at infinity. Also known as punctum remotum.

far region *See* Fraunhofer region. { ¦fär ¦rē·jən }

farringtonite [MINERAL] $Mg_3(PO_4)_2$ A col... white, or yellow phosphate mineral known only ... { 'far·iŋ·tə,nīt }

farsightedness *See* hypermetropia. { 'fär¦sīd·...

...ibution *See* flow field. { 'flō ,dis·trə,byü·shən }
...h *See* solifluction mantle. { 'flō ,ərth }
...ation [FL MECH] Equation for the calculation of ..., vapor, liquid) flow through conduits or channels; ... an interrelation of fluid properties (such as density ...ity), environmental conditions (such as temperature ...re), and conduit or channel geometry and conditions ...iameter, cross-sectional shape, or surface roughness). ...wā·zhən }
...wer [BOT] The characteristic reproductive structure of a ..., particularly if some or all of the parts are brightly ... { 'flaü·ər }
...sulfur [PHARM] One of three forms of pharma... sulfur, made by sublimation; the other two forms are ...ed sulfur and washed sulfur. Also known as sub...fur. { 'flaü·ərz əv 'səl·fər }
...tin *See* stannic oxide. { 'flaü·ərz əv 'tin }
... [FL MECH] The velocity and the density of a fluid ...ns of position and time. Also known as flow distri... { 'flō ,fēld }
... *See* strain figure. { 'flō ,fig·yər }
... [GEOL] Folding in beds, composed of relatively ... that assume any shape impressed upon them by ...uid surrounding rocks or by the general stress pattern ...formed zone; there are no apparent surfaces of slip. ...d }
... [COMPUT SCI] A directed graph that represents ...program, wherein a node in the graph corresponds to ...sequential code and branches correspond to decisions ...the program. [SYS ENG] *See* signal-low graph. ...f }
...d vibration [FL MECH] Structural and mechani...tions of structures immersed in or conveying fluid ...result of an interaction between the fluid-dynamic ...the inertia, damping, and elastic forces in the struc... { 'flō·in,dust vī'brā·shən }
...m concentration [MIN ENG] A concentration ...the fact that liquid films in laminar flow possess a ...which is not the same in all depths of the film; by this ...ghter particles of ore may be washed off while the ...rticles accumulate and are intermittently removed. ...ilm käns·ən'trā·shən }
...nace [MET] A furnace from which molten metal ...ped or drawn. { 'flō·iŋ 'fər·nəs }
...essure [PETRO ENG] Pressure at the bottom of an ...re (bottom-hole pressure) during normal oil produc... { ...iŋ ,presh·ər }
...essure gradient [PETRO ENG] The slope of ... pressure plotted against distance measured for ...liquid flow in a continuous-flow gas-lift oil well. ...resh·ər 'grād·ē·ənt }
...mperature factor [THERMO] Calculation correc...for gases flowing at temperatures other than that ...e flow equation is valid, that is, other than 60°F ... { 'flō·iŋ 'tem·prə·chər ,fak·tər }
...ll [PETRO ENG] Oil reservoir in which gas-drive ... sufficient to force oil flow up through and out of ... { 'flō·iŋ 'wel }
...ype [CYTOL] A karyotype that is based on flow ...measurements. { 'flō 'kar·ē·ə,tīp }
... [PETR] In an igneous rock, a layer which is differ...position or texture from adjacent layers. { 'flō ...
... [ENG] 1. The connecting line or arrow between ... a flow chart or block diagram. 2. Mark on a ...astic or metal article made by the meeting of two ...fronts during molding. Also known as weld line; ... [HYD] A contour of the water level around a .... [PETR] In an igneous rock, any internal struc...uced by parallel orientation of crystals, mineral ...inclusions. [PETRO ENG] A pipeline that takes oil ...e well or a series of wells to a gathering center.
... [MATER] Wavy surface marks on a thermoplastic ...ng due to improper flow of material into the mold. ...}
...rement [ENG] The determination of the quantity ...ther a liquid, a vapor, or a gas, that passes through ... or open channel. { 'flō ,mezh·ər·mənt }

flowmeter [ENG] An instrument used to measure pressure, flow rate, and discharge rate of a liquid, vapor, or gas flowing in a pipe. Also known as fluid meter. { 'flō,mēd·ər }

flow mixer [MECH ENG] Liquid-liquid mixing device in which the mixing action occurs as the liquids pass through it; includes jet nozzles and agitator vanes. Also known as line mixer. { 'flō ,mik·sər }

flow net [FL MECH] A diagram used in studying the flow of a fluid through a permeable substance (such as water through a soil structure) having two nests of curves, one representing the flow lines, which follow the path of the fluid, and the other the equipotential lines, which connect points of equal head. { 'flō ,net }

flow noise [ACOUS] 1. Pressure variations associated with a turbulent flow field that do not propagate away from the turbulent source but are sensed as sound by a receiver in direct contact or close to the turbulent flow. Also known as near-field noise. 2. More generally, any noise generated by turbulent fluid flow. { 'flō ,nóiz }

flow nozzle [ENG] A flowmeter in a closed conduit, consisting of a short flared nozzle of reduced diameter inset into the inner diameter of a pipe; used to cause a temporary pressure drop in flowing fluid to determine flow rate via measurement of static pressures before and after the nozzle. { 'flō ,näz·əl }

flow of variability [GEN] The movement of genetic variability within a population as a result of hybridization and segregation. { 'flō əv ,ver·ē·ə'bil·əd·ē }

flow pattern [FL MECH] Pattern of two-phase flow in a conduit or channel pipe, taking into consideration the ratio of gas to liquid and conditions of flow resistance and liquid holdup. { 'flō ,pad·ərn }

flow process [ENG] System in which fluids or solids are handled in continuous movement during chemical or physical processing or manufacturing. { 'flō ,präs·əs }

flow-programmed chromatography [ANALY CHEM] A chromatographic procedure in which the rate of flow of the mobile phase is periodically changed. { 'flō ,prō,gramd ,krō·mə'täg·rə·fē }

flow rate [FL MECH] Also known as rate of flow. 1. Time required for a given quantity of flowable material to flow a measured distance. 2. Weight or volume of flowable material flowing per unit time. { 'flō ,rāt }

flow-rating pressure [MECH ENG] The value of inlet static pressure at which the relieving capacity of a pressure-relief device is established. { 'flō ,rād·iŋ ,presh·ər }

flow reactor [CHEM ENG] A dynamic reactor system in which reactants flow continuously into the vessel and products are continuously removed, in contrast to a batch reactor. { 'flō rē,ak·tər }

flow regime [HYD] A range of streamflows having similar bed forms, flow resistance, and means of transporting sediment. { 'flō rə,zhēm }

flow resistance [FL MECH] 1. Any factor within a conduit or channel that impedes the flow of fluid, such as surface roughness or sudden bends, contractions, or expansions. 2. *See* viscosity. { 'flō ri,zis·təns }

flow rock [PETR] An igneous rock that had been liquid. { 'flō ,räk }

flow separation *See* boundary-layer separation. { 'flō ,sep·ə,rā·shən }

flow sheet *See* flow chart. { 'flō ,shēt }

flow shop [IND ENG] A manufacturing facility in which machine tools and robots are employed in the same manner on all jobs. { 'flō ,shäp }

flow slide [GEOL] A slide of waterlogged material in which the slip surface is not well defined. { 'flō ,slīd }

flow soldering [ENG] Soldering of printed circuit boards by moving them over a flowing wave of molten solder in a solder bath; the process permits precise control of the depth of immersion in the molten solder and minimizes heating of the board. Also known as wave soldering. { 'flō ,säd·ə·riŋ }

flowstone [GEOL] Deposits of calcium carbonate that accumulated against the walls of a cave where water flowed on the rock. { 'flō,stōn }

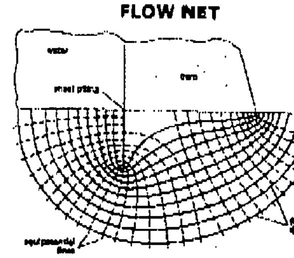
flow stress [MECH] The stress along one axis at a given value of strain that is required to produce plastic deformation. { 'flō ,stres }

flow string [PETRO ENG] Total length of oil- or gas-well

FLOW-INDUCED VIBRATION

Flutter of a polyethylene tube (garden hose) conveying fluid, an example of flow-induced vibration. The tube is illuminated by a stroboscope to show its motion.

FLOW NET



Flow net indicated under the cutoff wall of a dam. (*From D. P. Krynine, Soil Mechanics, 2d ed., McGraw-Hill, 1947*)

FLOW NOZZLE

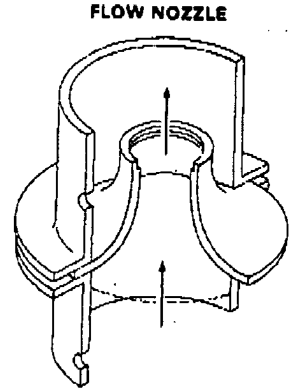


Diagram of a flow nozzle. Arrows indicate direction of fluid flow.

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PROPERTIES OF WATER IN THE RANGE 0–100 °C

This table summarizes the best available values of the density, specific heat capacity at constant pressure (C_p), vapor pressure, viscosity, thermal conductivity, dielectric constant, and surface tension for liquid water in the range 0 – 100 °C. All values (except vapor pressure) refer to a pressure of 100 kPa (1 bar). The temperature scale is IPTS-68.

References

1. L. Harr, J. S. Gallagher, and G. S. Kell, *NBS/NRC Steam Tables*, Hemisphere Publishing Corp., New York, 1984.
2. K. N. Marsh, Ed., *Recommended Reference Materials for the of Physicochemical Properties*, Blackwell Scientific P Oxford, 1987.
3. J. V. Sengers and J. T. R. Watson, Improved International for the viscosity and thermal conductivity of water subst *Chem. Ref. Data*, 15, 1291, 1986.
4. D. G. Archer and P. Wang, The dielectric constant of wate Hückel limiting law slopes, *J. Phys. Chem. Ref. Data*, 19,
5. N. B. Vargaftik, et al., International tables of the surfac water, *J. Phys. Chem. Ref. Data*, 12, 817, 1983.

t °C	Density g/cm³	C_p J/g K	Vap. pres. kPa	Visc. μPa s	Ther. cond. mW/K m	Diel. const.	Surf. ten. mN/m
0	0.99984	4.2176	0.6113	1793	561.0	87.90	75.64
10	0.99970	4.1921	1.2281	1307	580.0	83.96	74.23
20	0.99821	4.1818	2.3388	1002	598.4	80.20	72.75
30	0.99565	4.1784	4.2455	797.7	615.4	76.60	71.20
40	0.99222	4.1785	7.3814	653.2	630.5	73.17	69.60
50	0.98803	4.1806	12.344	547.0	643.5	69.88	67.94
60	0.98320	4.1843	19.932	466.5	654.3	66.73	66.24
70	0.97778	4.1895	31.176	404.0	663.1	63.73	64.47
80	0.97182	4.1963	47.373	354.4	670.0	60.86	62.67
90	0.96535	4.2050	70.117	314.5	675.3	58.12	60.82
100	0.95840	4.2159	101.325	281.8	679.1	55.51	58.91
Ref.	1–3	2	1, 3	3	3	4	5

ENTHALPY OF VAPORIZATION OF WATER

The enthalpy (heat) of vaporization of water is tabulated as a function of temperature on the IPTS-68 scale.

Reference

Marsh, K. N., Ed., *Recommended Reference Materials for Physicochemical Properties*, Blackwell, Oxford, 1987.

t °C	$\Delta_{vap}H$ kJ/mol	t °C	$\Delta_{vap}H$ kJ/mol
0	45.054	200	34.962
25	43.990	220	33.468
40	43.350	240	31.809
60	42.482	260	29.930
80	41.585	280	27.795
100	40.657	300	25.300
120	39.684	320	22.297
140	38.643	340	18.502
160	37.518	360	12.966
180	36.304	374	2.066

VAPOR PRESSURE OF WATER FROM 0 TO 370°C

This table gives the vapor pressure of water at intervals of 1° C from the melting point to the critical point.

Reference

Haar, L., Gallagher, J. S., and Kell, G. S., *NBS/NR*[illegible] Hemisphere Publishing Corp., New York, 1984.

t/°C	*P*/kPa	*t*/°C	*P*/kPa	*t*/°C	*P*/kPa	*t*/°C	*P*/kPa
0	0.61129	52	13.623	104	116.67	156	[illegible]
1	0.65716	53	14.303	105	120.79	157	[illegible]
2	0.70605	54	15.012	106	125.03	158	[illegible]
3	0.75813	55	15.752	107	129.39	159	[illegible]
4	0.81359	56	16.522	108	133.88	160	[illegible]
5	0.87260	57	17.324	109	138.50	161	[illegible]
6	0.93537	58	18.159	110	143.24	162	[illegible]
7	1.0021	59	19.028	111	148.12	163	[illegible]
8	1.0730	60	19.932	112	153.13	164	[illegible]
9	1.1482	61	20.873	113	158.29	165	[illegible]
10	1.2281	62	21.851	114	163.58	166	[illegible]
11	1.3129	63	22.868	115	169.02	167	[illegible]
12	1.4027	64	23.925	116	174.61	168	[illegible]
13	1.4979	65	25.022	117	180.34	169	[illegible]
14	1.5988	66	26.163	118	186.23	170	[illegible]
15	1.7056	67	27.347	119	192.28	171	[illegible]
16	1.8185	68	28.576	120	198.48	172	[illegible]
17	1.9380	69	29.852	121	204.85	173	[illegible]
18	2.0644	70	31.176	122	211.38	174	[illegible]
19	2.1978	71	32.549	123	218.09	175	[illegible]
20	2.3388	72	33.972	124	224.96	176	[illegible]
21	2.4877	73	35.448	125	232.01	177	[illegible]
22	2.6447	74	36.978	126	239.24	178	[illegible]
23	2.8104	75	38.563	127	246.66	179	[illegible]
24	2.9860	76	40.205	128	254.25	180	[illegible]
25	3.1690	77	41.905	129	262.04	181	[illegible]
26	3.3629	78	43.665	130	270.02	182	[illegible]
27	3.5670	79	45.487	131	278.20	183	[illegible]
28	3.7818	80	47.373	132	286.57	184	[illegible]
29	4.0078	81	49.324	133	295.15	185	[illegible]
30	4.2455	82	51.342	134	303.93	186	[illegible]
31	4.4953	83	53.428	135	312.98	187	[illegible]
32	4.7578	84	55.585	136	322.14	188	[illegible]
33	5.0335	85	57.815	137	331.57	189	[illegible]
34	5.3229	86	60.119	138	341.22	190	[illegible]
35	5.6267	87	62.499	139	351.09	191	[illegible]
36	5.9453	88	64.958	140	361.19	192	[illegible]
37	6.2795	89	67.496	141	371.53	193	[illegible]
38	6.6298	90	70.117	142	382.11	194	[illegible]
39	6.9969	91	72.823	143	392.92	195	[illegible]
40	7.3814	92	75.614	144	403.98	196	[illegible]
41	7.7840	93	78.494	145	415.29	197	[illegible]
42	8.2054	94	81.465	146	426.85	198	[illegible]
43	8.6463	95	84.529	147	438.67	199	[illegible]
44	9.1075	96	87.688	148	450.75	200	[illegible]
45	9.5898	97	90.945	149	463.10	201	[illegible]
46	10.094	98	94.301	150	475.72	202	[illegible]
47	10.620	99	97.759	151	488.61	203	[illegible]
48	11.171	100	101.32	152	501.78	204	[illegible]
49	11.745	101	104.99	153	515.23	205	[illegible]
50	12.344	102	108.77	154	528.96	206	[illegible]
51	12.970	103	112.66	155	542.99	207	[illegible]

VISCOSITY OF LIQUIDS

...scosity of some common liquids at temperatures ...100°C is given in this table. Values were derived ...ental data to suitable expressions for the tem- ...ance. The substances are arranged by molecular ...odified Hill order (see Preface). All values are ...millipascal seconds (mPa s); this unit is identical

... correspond to a nominal pressure of 1 atmos- ...given at a temperature above the normal boiling ...ble pressure is understood to be the vapor pres- ...at that temperature. A few values are given at a ...tly below the normal freezing point; these refer ...d liquid.

...anges from 1% in the best cases to 5 to 10% in the ...itional significant figures are included in the table ...olation.

References

1. Viswanath, D. S. and Natarajan, G., *Data Book on the Viscosity of Liquids*, Hemisphere Publishing Corp., New York, 1989.
2. Daubert, T. E., Danner, R. P., Sibul, H. M., and Stebbins, C. C., *Physical and Thermodynamic Properties of Pure Compounds: Data Compilation*, extant 1994 (core with 4 supplements), Taylor & Francis, Bristol, PA (also available as database).
3. Ho, C. Y., Ed., *CINDAS Data Series on Material Properties*, Vol. V-1, *Properties of Inorganic and Organic Fluids*, Hemisphere Publishing Corp., New York, 1988.
4. Stephan, K. and Lucas, K., *Viscosity of Dense Fluids*, Plenum Press, New York, 1979.
5. Vargaftik, N. B., *Tables of Thermophysical Properties of Liquids and Gases*, 2nd ed., John Wiley, New York, 1975.

Name	Viscosity in mPa s					
	-25°C	0°C	25°C	50°C	75°C	100°C
...s not containing carbon						
Bromine		1.252	0.944	0.746		
Trichlorosilane		0.415	0.326			
Phosphorous trichloride	0.870	0.662	0.529	0.439		
Tetrachlorosilane			99.4	96.2		
Water		1.793	0.890	0.547	0.378	0.282
Hydrazine			0.876	0.628	0.480	0.384
Mercury			1.526	1.402	1.312	1.245
Nitrogen dioxide		0.532	0.402			
...s containing carbon						
Trichlorofluoromethane	0.740	0.539	0.421			
Tetrachloromethane		1.321	0.908	0.656	0.494	
Carbon disulfide		0.429	0.352			
Tribromomethane			1.857	1.367	1.029	
Trichloromethane	0.988	0.706	0.537	0.427		
Hydrogen cyanide		0.235	0.183			
Dibromomethane	1.948	1.320	0.980	0.779	0.652	
Dichloromethane	0.727	0.533	0.413			
Formic acid			1.607	1.030	0.724	0.545
Iodomethane		0.594	0.469			
Formamide		7.114	3.343	1.833		
Nitromethane	1.311	0.875	0.630	0.481	0.383	0.317
Methanol	1.258	0.793	0.544			
Methylamine	0.319	0.231				
1,1,2-Trichlorotrifluoro-ethane	1.465	0.945	0.656	0.481		
Tetrachloroethylene		1.114	0.844	0.663	0.535	0.442
Trichloroethylene		0.703	0.545	0.444	0.376	
Pentachloroethane		3.761	2.254	1.491	1.061	
Trifluoroacetic acid			0.808	0.571		
cis-1,2-Dichloroethylene	0.786	0.575	0.445			
trans-1,2-Dichloroethylene	0.522	0.398	0.317	0.261		
1,1,1,2-Tetrachloroethane	3.660	2.200	1.437	1.006	0.741	0.570
1-Chloro-1,1-difluoro-ethane	0.477	0.376				
Acetyl chloride			0.368	0.294		
1,1,1-Trichloroethane	1.847	1.161	0.793	0.578	0.428	
Acetonitrile		0.400	0.369	0.284	0.234	
1,2-Dibromoethane			1.595	1.116	0.837	0.661